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COMPRESSIVE AND TENSILE CREEP OF 7075-T6 AND 2024-T3 ALUMINUM-ALLOY SHEET

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SUMMARY

Results are presented of compressive and tensile creep tests of 7075-T6 and 2024-T3 aluminum-alloy sheet at 300°, 375°, 450°, and 600° F. Compressive and tensile creep are compared and found to be essentially the same for both materials in the primary and secondary creep regions except for 2024-T3 aluminum-alloy sheet at 300° and 375° F where the compressive creep was less. At 300° F where aging and prestraining effects were particularly evident, compressive creep was markedly less than tensile creep.

INTRODUCTION

The need for compressive creep data for applications in which compressive creep or creep buckling may be a consideration has led to a number of investigations to determine the compressive creep properties of various structural materials (for example, refs. 1 to 5). Some additional data on compressive creep together with results on creep buckling of columns and compressed plates may be found in the literature, such as references 6 to 9.

Inasmuch as compressive creep data are not generally available and are difficult to obtain, common practice has been to use tensile data for applications involving compression. This substitution cannot be made with any degree of assurance, however, unless the relation between tensile and compressive creep is known.

A review of references 1 to 7, in which some comparisons of compressive and tensile creep are given for a wide variety of materials, indicates that compressive creep may be about the same or more or less than tensile creep, depending upon the material, temperature, and stress. On the basis of the present state of knowledge, there does not appear to be any simple relation between compressive and tensile creep which can be generally applied.

In order to investigate this matter further, compressive and tensile creep tests were made on 7075-T6 and 2024-T3 aluminum-alloy sheet at the Langley Research Center of the National Aeronautics and Space Administration. The data were obtained at 300°, 375°, 450°, and 600° F and covered times from about 10 to 100 hours. The investigation was carried out with a 20,000-pound-capacity compression creep testing machine and other new equipment designed for this purpose.

TEST PROCEDURE AND EQUIPMENT

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Specimens

The tensile and compressive stress-strain and creep specimens were cut from 0.125-inch-thick 7075-T6 and 2024-T3 aluminum-alloy sheet with the longitudinal axis of the specimen parallel to the rolling direction. The specimens for each material were taken from a single sheet.

The dimensions of the specimens are shown in figure 1. The tensile stress-strain and the tensile creep specimens are identical. The width of the compressive creep specimen (0.80 inch) was made slightly less than the width for the compressive stress-strain specimen (1.00 inch) in order to reduce the possibility of local buckling, as the creep specimen was unsupported except at the side edges.

Method of Testing

Conventional short-time elevated-temperature tensile and compressive stress-strain tests were conducted in the manner and with the equipment described in reference 10. The specimen was exposed to the test temperature for 1/2 hour before the load was applied. A strain rate of 0.002 per minute was used throughout the tests. The tests were made in hydraulic testing machines, and the strains were measured over a 1-inch gage length. The specimen temperature was controlled within ±2° F.

The tensile creep tests were made in conventional tensile deadweight-type creep testing machines equipped with 1,800° F furnaces. Each specimen was exposed to the test temperature for 1/2 hour before the load was applied slowly in small increments. Strains were measured over a 1-inch gage length with an extensometer system similar to that used for the tensile stress-strain tests. The temperature of the specimen and the strain were measured on a two-channel strip-type recorder. The specimen temperature was controlled within ±2° F.

The compressive creep tests were made in a 20,000-pound-capacity, deadweight-type compressive creep testing machine designed for this purpose (fig. 2). The specimens were supported in a V-groove fixture shown in figure 3 and on the right in figure 4. A description of this machine and other auxiliary equipment is given in the appendix. Each specimen was exposed to the test temperature for 1/2 hour before the load was applied in small increments. Strains were measured over a 1-inch gage length with two linear differential transformer gages. The specimen temperature and strain were measured on a two-channel strip-type recorder. The specimen temperature was maintained within ±2° F. Brief descriptions of some other current methods for making creep tests in compression are given in reference 11.

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TEST RESULTS AND DISCUSSION

Compressive and Tensile Stress-Strain Properties

The results of the elevated-temperature compressive and tensile stress-strain tests for 7075-T6 and 2024-T3 aluminum-alloy sheet are given in tables 1 and 2, respectively; representative stress-strain curves are shown in figure 5. These data are for 1/2-hour exposure and a constant strain rate of 0.002 throughout the test. The compressive stress-strain curves for 2024-T3 aluminum-alloy sheet were taken from reference 12 because the test equipment was dismantled and unavailable at the time. These compressive stress-strain curves may be considered representative of the material used for these tests, however, because of the close agreement found at room temperature between a compressive stress-strain curve obtained for the material used in this investigation and that obtained from reference 12 (fig. 5).

In general, the compressive stress-strain curves are more rounded than those in tension for both materials (fig. 5). In the plastic region, the compressive stress-strain curves for 7075-T6 aluminum alloy are for the most part slightly lower than in tension throughout the temperature range. For 2024-T3 aluminum alloy, however, the compressive stress-strain curves at 80°, 300°, and 375° F are substantially lower than in tension in the plastic range, but at 450° and 600° F the compressive and tensile stress-strain curves are almost the same.

Fixture Effects

Some preliminary creep tests of 7075-T6 aluminum alloy were made to determine the effect of fixture tightness on the compressive creep. The results of these tests at 300° and 450° F are shown in figure 6. The tightness was varied from a minimum or snug condition to very tight by turning down the nuts on the lock washers on the supporting bolts of the fixture (fig. 4) by fractional intervals up to 1/2 turn. In the snug condition, the specimen could be pushed through the fixture by hand, but after 1/2 turn the specimen was very tightly held and an appreciable force was necessary to move it. The forces required to slide the specimen through the fixture at room temperature varied from about 10 pounds for the snug condition to about 50 pounds for a tightness of 1/2 turn.

The results (fig. 6) showed no regular trend or effect of fixture tightness on the compressive creep. In some tests there was an indication that the greatest creep occurred when the tightness was the least, but in other tests as much or more creep occurred when the specimen was more tightly held. The scatter in the results for any particular tightness, stress, and temperature was about the same as the spread obtained for the tests at various tightnesses. In general, the scatter in the results is small, especially at 450° F, and the effects of fixture tightness apparently are not pronounced. Fixture tightness, however, can be expected to be a matter of some concern for tests of materials in which the stresses and loads may be very small. In such cases, frictional and restraining effects may be relatively large and the tightness should be kept to a minimum.

Some compressive stress-strain tests of 7075-T6 aluminum-alloy sheet were also made at room temperature with the V-groove fixture to determine whether the tightness adjustment was critical in this type of application. The results of these tests indicated that variations in tightness had little effect on the compressive stress-strain curve for this material. The V-type fixture, which supports the specimen at the outside edges, appears to be relatively free from clamping effects which may be present in the type of fixture ordinarily used for compression stress-strain tests where the specimen is supported on the side faces. In general, however, for either compressive stress-strain tests or compressive creep tests, it is desirable to use a minimum tightness with the V-groove fixture in order to eliminate possible tightness effects, particularly for tests involving small loads and stresses.

Strains are limited to about 3 to 4 percent with the V-groove fixture because only a small length of the specimen can be left unsupported above the fixture and because localized plastic deformation occurs at the top of the specimen when the strain becomes large. This plastic deformation results in a widening of the specimen just above the fixture so that the top edges of the fixture tend to cut into the side corner edges of the specimen as it is compressed. The plastic region is readily visible after strains of several percent and extends about 1/8 inch down from the top at the middle of the side faces of the specimen. Some of the objectionable effects of this widening at the top of the specimen are overcome by rounding off the side corner edges of the specimen slightly at the top.

The use of the V-groove fixture is limited to fairly thick sheet, that is, the width-thickness ratio must be small enough to avoid buckling.

The allowable minimum thickness will depend on the stress and temperature ranges covered by the tests. The width-thickness ratio for the compressive creep specimens used in these tests was approximately 6.4, and no indication of local buckling was observed.

Compressive and Tensile Creep for

7075-T6 Aluminum-Alloy Sheet

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The results of the compressive and tensile creep tests of 7075-T6 aluminum-alloy sheet are shown in figures 7 to 13, and these data are summarized in tables 3 and 4, respectively.

Representative creep strain-time curves for compression and tension at 300°, 375°, 450°, and 600° F are shown in figures 7 to 10, respectively. Approximately the same stress range was covered in tension as in compression and in many cases the stresses are the same. For comparative purposes, the tensile and compressive creep curves for the same temperature are shown together in each figure. In addition, two of the tensile creep curves for each temperature are transposed and shown with the compressive creep curves by the dashed-line curves so that a direct comparison can be made. The creep strain is the time-dependent component of the strain which occurs after the load is applied. A comparison of the compressive and tensile creep results for this material (figs. 7 to 10) show generally that creep strains in compression and tension are nearly the same except in the tertiary region where the tensile creep strains are greater. At 600° F, some variations are apparent, inasmuch as the compressive creep in the primary and secondary regions is either the same or more or less than the tensile creep. Some irregularities in the creep curves are also apparent at short times and very small creep strains (for example, fig. 8), but these would not be discernible if uniform scales had been used in the plots.

The tertiary creep region may be recognized in creep strain-time curves plotted on logarithmic paper (such as figs. 7 to 10) as beginning at the time when the slope of the curve exceeds unity. If comparatively little primary creep strain occurs, the beginning of the secondary region may be taken as the time when the slope of the curve becomes unity. If a large amount of primary creep occurs, however, the dividing line between primary and secondary creep cannot be readily determined in such plots, because the slope of the curve may be less than unity even though steady creep is taking place.

The stress-time curves in compression and tension at 300°, 375°, 450°, and 600° F are shown in figure 11 for creep strains of 0.1, 0.2, 0.5, and 1.0 percent. To aid in the comparison of the tensile and compressive results, the tensile curves for 0.2-percent creep strain are superimposed on the compressive curves in figure 11(a). Except at 300° F, the tensile and compressive results for 0.1-, 0.2-, and 0.5-percent creep strain are in fairly close agreement. At 300° F, tensile and compressive creep are about the same at 40 ksi but differ somewhat above and below this stress. The tensile stress for 1.0-percent creep strain, as compared with the compressive stress taken at the same time and temperature, is somewhat less at 300° and 375° F, slightly greater at 450° F, and about the same at 600° F.

A comparison of the minimum creep rates in compression and tension
at 300°, 375°, 450°, and 600° F is shown in figure 12. The tensile L
results (fig. 12(b)) are superimposed in figure 12(a) to provide a direct 3
comparison. Except at 300° F where creep rates in compression are a 3
little less than in tension, the tensile and compressive stresses for a 0
given minimum creep rate and temperature are almost the same.

For convenience in various possible structural applications involving compressive creep and creep buckling over short periods, the compressive creep results for 7075-T6 aluminum-alloy sheet are also shown in the form of isochronous compressive stress-strain curves in figure 13 for 0.1, 1, and 10 hours at 300°, 375°, 450°, and 600° F. The strain is the total strain which includes the initial elastic and plastic strains due to loading as well as the time-dependent creep strain.

The various comparisons of compressive and tensile creep (figs. 7 to 12) are all consistent in showing that primary and secondary creep are approximately the same in compression and in tension for this material. In the investigation of the compressive strength and creep of plates of 7075-T6 aluminum alloy (ref. 7), however, compressive creep was found to be less than tensile creep. The compressive creep tests were made in a long V-groove fixture designed primarily for compressive strength and creep buckling tests of plates. There is a possibility that the use of long narrow compressive creep specimens may have given rise to some restraining effects. The compressive creep at 450° F (ref. 7) was less than that obtained in this investigation for this material at that temperature.

Compressive and Tensile Creep for

2024-T3 Aluminum-Alloy Sheet

The results of the compressive and tensile creep tests of 2024-T3 aluminum-alloy sheet are presented in figures 14 to 20 and in tables 5 and 6, respectively.

Representative creep strain-time curves for compression and tension at 300°, 375°, 450°, and 600° F are shown in figures 14 to 17, respectively.

As shown in figure 14(a) by the transposed tensile creep curve for 50 ksi, compressive creep at 300° F is very much less than tensile creep for all stages of creep. At 375° F (fig. 15) the tensile creep is also greater than the compressive creep, but the difference is not nearly as large as at 300° F. At 450° F (fig. 16), compressive and tensile creep in the primary and secondary regions are about the same. At 600° F (fig. 17), the tensile creep is slightly greater or about the same as the compressive creep. Tensile creep in the tertiary region is greater than the compressive creep at all temperatures.

Stress-time curves in compression and tension for creep strains of 0.1, 0.2, 0.5, and 1.0 percent at 300°, 375°, 450°, and 600° F are shown in figure 18. At 450° and 600° F the stresses for creep strains up to 1.0 percent are practically the same or slightly less in tension than in compression. At 300° and 375° F, however, such a close correspondence does not exist, and the stress for a given creep strain in tension is considerably less than in compression, particularly at 300° F.

Minimum creep rates in compression and tension at 300°, 375°, 450°, and 600° F are shown in figure 19. Minimum creep rates at 450° and 600° F are practically the same in compression and tension, as shown by the superimposed curves in figure 19(a). At 300° and 375° F, however, minimum creep rates in tension are considerably greater than in compression, especially at 300° F. The minimum creep rates in compression at 300° F (fig. 19(a)) are those associated with the retarded creep occurring after about 60 hours; steady creep also occurred from about 30 to 50 hours in some of these tests; the minimum creep rates in this region were somewhat greater than those shown in figure 19(a).

The compressive creep results for 2024-T3 aluminum-alloy sheet for 0.1, 1, and 10 hours at 300°, 375°, 450°, and 600° F are also shown in the form of isochronous compressive stress-strain curves (fig. 20). The strain is the total strain which includes the initial elastic and plastic strains and the time-dependent creep strain.

All the various comparisons between compressive and tensile creep for 2024-T3 aluminum-alloy sheet (figs. 14 to 19) show that creep in compression and tension is approximately the same at 450° and 600° F except in the tertiary region where the tensile creep is greater. At 300° and 375° F, however, the material is more creep resistant in compression, particularly at 300° F. These results are in general agreement with the conclusions of references 1, 3, and 6 with regard to tensile and compressive creep for this material. On the other hand, comparisons of compressive and tensile creep for some wrought, cast, and cermet materials from 1,350° to 1,800° F (ref. 5) showed that wrought bar materials might be less creep resistant in compression than in tension. This is contrary to the results obtained in this investigation for two wrought aluminum-alloy sheet materials in which the compressive creep was either about the same or less than the tensile creep.

The pronounced difference in creep behavior in compression and tension at 300° (fig. 14) is probably due to both prestraining and aging effects. Examination of the compressive creep strain curves (fig. 14(a)) shows an initial retarded creep strain region, followed by an accelerated creep region, and then a final period of retarded creep. The initial retarded creep region may be the result of prestraining effects arising on loading, because the stresses (45 to 53.75 ksi) are well beyond the elastic range (fig. 5). The following accelerated creep region probably arises from a deterioration of the prestraining effects with temperature and time. The last retarded creep region is probably due to aging effects which begin to be important after about 10 hours at this temperature. L
(See fig. 5 of ref. 12.) The tensile creep strain curves (fig. 14(b)), 3
on the other hand, have very different characteristics from those in com- 3
pression; rapid creep occurs initially and this is followed by a rela- 0
tively long period of retarded creep in which creep almost comes to a halt. The initial rapid creep may be due to the high stresses (47.5 to 53.75 ksi) and the absence of strain hardening effects which were evident in compression. The final retarded creep undoubtedly arises from aging effects. Most of the large difference between the tensile and compressive creep occurs in the first few hours. The reason for this large difference is not known.

Aging effects under tensile and compressive loading were also found for type 347 stainless steel at $1,100^\circ$ F (ref. 13). The effects were more prolonged in compression than in tension with the result that the creep strength was also greater in compression than in tension for this material.

A comparison of the compressive and tensile creep curves for 2024-T3 aluminum-alloy sheet (figs. 14 to 17) with those for 7075-T6 aluminum-alloy sheet (figs. 7 to 10) shows that the former alloy is considerably more creep resistant than the latter in the temperature range from 300° to 600° F for times up to about 100 hours.

CONCLUDING REMARKS

The results of this investigation of the compressive and tensile creep of 7075-T6 and 2024-T3 aluminum-alloy sheet indicate that compressive and tensile creep may be essentially the same in the primary and secondary creep regions for some materials which are not subject to aging or prestraining effects. For 7075-T6 aluminum-alloy sheet, the correspondence between compressive and tensile creep is close at 300° to 600° F. This is also the case for 2024-T3 aluminum-alloy sheet at 450° and 600° F. At 300° and 375° F, however, the compressive creep for this latter material is less than the tensile creep, especially at 300° F. For both materials tensile creep in the tertiary region is greater in general than compressive creep. The assumption that tensile creep can be substituted for compressive creep may be valid only in the first and second stages of creep for materials which are not subject to appreciable prestraining, aging, or other complicating effects.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 20, 1959.

APPENDIX

DESCRIPTION OF EQUIPMENT FOR COMPRESSIVE CREEP TESTS

Compressive Creep Testing Machine

A general view of the test setup (fig. 2) shows the 20,000-pound-capacity compressive creep testing machine and auxiliary equipment.

The compressive creep testing machine is essentially a deadweight lever-type loading machine having an upper adjustable fixed platen mounted on a four-post frame and a lower movable platen. The upper platen may be positioned by moving the nuts which clamp it to the threaded posts. The lower platen is guided so that it can move vertically. This is accomplished by means of four sets of adjustable roller bearings mounted at both the top and the bottom of the base of the machine, which guide a heavy cylinder attached rigidly to the bottom of the platen. The load is applied to this platen by the two tension rods which are connected to the lever system through a yoke at the top. Knife edges are employed at the fulcrum and at the ends of the lever. A weight cage is hung on the outward side of the lever. Friction in the loading system did not amount to more than 1 to 2 pounds. The top plate, upper platen, and base, which are clamped to the four posts by heavy nuts (fig. 2), constitute a very rigid frame. Rigidity is required to insure continued accurate alinement of the loading rams under compression loading.

Loading Rams

The upper and lower loading rams which carry the load to the specimen can be seen in figures 2 and 3. The upper ram is attached to the upper fixed platen through an adjustable spherical seat which provides a method for alining the upper ram with the top of the specimen. The lower ram is mounted on a base plate which rests on the top of the lower platen. The load-bearing surface of each ram consists of an insert of Haynes Stellite 98M2 alloy, a high hot-hardness, cobalt-chromium tungsten alloy. The rams are hollow so as to reduce the heat loss. Openings are provided in the lower ram for the extensometer rods and strain-gage transfer arms to pass through. The rams were made of type 316 stainless steel except for the load inserts.

Specimen Fixture

The specimen is supported in a V-groove type fixture which supports the specimen on the side edges instead of on the faces as in the case of the compression fixture ordinarily used for stress-strain tests. Two types of V-groove fixtures are shown in figure 4. The fixture at the left employs supporting plates which are slightly longer than the specimen and a subpress having an extension which fits down into the grooves of the fixture in order to load the specimen. The specimen is supported over its full length in this fixture. The subpress tended to cut into the top of the specimen, however, with the result that the top of the specimen would bind in the fixture. Because this difficulty could not be overcome, the simpler type of fixture shown on the right (fig. 4) was used; this fixture does not require a subpress inasmuch as the specimen extends about 0.04 inch above the fixture. Each supporting plate has a 45° V-groove. The ends of the supporting plates are squared off in the direction normal to the plane of the specimen and tapered in the other direction. The fixture thus supports the specimen at right angles to the bearing surface but does not interfere with the uniform seating of the specimen across its width. The holes through which the bolts pass are oversize so that the fixture alines itself readily with the specimen. The fixtures are made of Haynes Stellite 98M2 alloy, the support bolts of Inconel, and the spring washers of heat-treated Inconel X. The lock washers permit some adjustment to the lateral pressure and minimize clamping effects which might arise from differences in thermal expansion of the specimen and the fixture and from Poisson's ratio.

Extensometer System

Various portions of the extensometer system can be seen in figures 2 and 3. Two linear differential transformer strain gages are mounted on strain transfer devices which keep the gages well away from and below the furnace. Flexure plates are used at the fulcrum of these devices which are similar to those used in the compression test. (See fig. 3 of ref. 10.) The gages are operated by four extensometer rods which extend down through the ram. The gage point attached to the upper end of each rod (fig. 3) is fashioned from a small piece of stainless-steel sheet which is welded to the end of the extensometer rod. The rounded portion in contact with the specimen, together with the gage point, stabilizes the gage point against rotation. Inconel X springs (fig. 3) are used to clip the gage points on the specimen. The gage points seat in small punch marks put on the specimen before it is placed in the fixture.

Heating Equipment

The exterior air furnace (fig. 2) is a two-part furnace; the lower part may be dropped down so that the fixture and specimen can be inserted. This furnace is heated by two 450-watt Chromalox heating elements. Four cartridge-type heating elements are also incorporated at the loading ends of both the top and bottom rams. These heating elements (each 180-watt capacity) are located adjacent to loading-block inserts and positioned diametrically to give each ram a total capacity of 720 watts. The voltage to the three heating units is regulated by the three Variacs and the controller shown on the right-hand side of figure 2. The vane-type controller regulates all three heating units. Proportional voltage regulation is used. The temperature of the specimen can be maintained within $\pm 2^{\circ}$ F with this system. The thermocouple operating the controller is located adjacent to one of the Chromalox heating elements of the air furnace, so that it acts as a sensing device for the controller. This furnace equipment is adequate for tests up to $1,000^{\circ}$ F.

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TABLE 1.- COMPRESSIVE AND TENSILE PROPERTIES OF 7075-T6

ALUMINUM-ALLOY SHEET AT ELEVATED TEMPERATURES

Temp., °F	Compression		Tension			
	Yield strength, ksi (a)	Young's modulus, psi	Yield strength, ksi (a)	Tensile strength, ksi	Young's modulus, psi	Elongation in 2 inches, percent
80	74.4	10.6×10^6	73.6	80.0	----------	14
	74.0	10.3	73.3	79.4	10.3×10^6	12
300	57.0	9.1	59.6	59.6	9.6	17
	57.4	9.2	59.0	59.3	9.4	18
450	25.2	7.5	25.8	26.2	8.5	13
	23.9	7.9	25.1	25.5	8.6	14
600	8.1	6.3	9.3	9.4	7.1	33
	8.1	6.3	8.8	9.1	----------	34
	7.9	6.4				

[a] 0.2-percent offset.

TABLE 2.- COMPRESSIVE AND TENSILE PROPERTIES OF 2024-T3

ALUMINUM-ALLOY SHEET AT ELEVATED TEMPERATURES

Temp., °F	Compression (from ref. 12)		Tension			
	Yield strength, ksi (a)	Young's modulus, psi	Yield strength, ksi (a)	Tensile strength, ksi	Young's modulus, psi	Elongation in 2 inches, percent
80	43.5	10.5×10^6	53.6 52.9	71.5 71.6	10.2×10^6 9.7	16 16
300	41.3	10.0	---- 47.0	59.0 59.0	9.7 8.2	14 15
375	39.7	9.5	46.7 46.8	56.2 54.1	8.7 9.3	10 9
450	39.2	9.1	37.3 40.3	38.0 40.7	8.0 8.8	8 8
600	16.7	7.2	15.6 15.5	17.2 16.0	6.8 7.2	14 13

[a]0.2-percent offset.

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TABLE 3.- COMPRESSIVE CREEP RESULTS FOR 7075-T6

ALUMINUM-ALLOY SHEET

Temperature, °F	Stress, ksi	Minimum creep rate, hr^{-1}	Time, hr, for creep strains of -			
			0.1 percent	0.2 percent	0.5 percent	1.0 percent
300	35.0	3.4×10^{-5}	6.5	33.5	170	-----
	35.0	2.9×10^{-5}	----	-----	-------	-----
	40.0	6.4×10^{-5}	1.4	8.8	58	120
	40.0	6.8×10^{-5}	----	-----	-------	-----
	45.0	1.7×10^{-4}	.33	2.6	19.8	52
	45.0	1.6×10^{-4}	----	-----	-------	-----
	50.0	4.9×10^{-4}	.08	.4	4.2	14.8
	50.0	7.3×10^{-4}	----	-----	-------	-----
	[a]55.0	3.5×10^{-3}	.04	.14	.65	2.4
	[a]55.0	5.5×10^{-3}	----	.07	.40	1.5
	[a]55.0	3.6×10^{-3}	----	.08	.50	2.1
	[a]55.0	2.6×10^{-3}	.06	.13	.77	2.8
375	17.0	5.8×10^{-5}	4.5	15.5	64	132
	20.0	1.5×10^{-4}	3.2	8.2	27	51
	22.5	2.4×10^{-5}	1.9	5.7	17.5	30
	25.0	4.0×10^{-4}	1.5	4.2	10.2	16.5
	30.0	6.1×10^{-4}	.8	2.4	5.7	8.6
450	[a]10.0	9.2×10^{-5}	3.3	12.5	40	75
	[a]10.0	9.8×10^{-5}	1.8	10.5	40	75
	[a]10.0	1.1×10^{-4}	1.4	7.9	36	66
	13.0	3.7×10^{-4}	.68	2.4	9.5	16.5
	[a]15.0	6.6×10^{-4}	.42	1.6	4.8	7.3
	[a]15.0	7.1×10^{-4}	.39	1.4	5.2	9.0
	[a]15.0	6.5×10^{-4}	.50	1.9	5.0	8.2
	[a]15.0	6.3×10^{-4}	.45	1.6	5.0	8.9
600	4.0	9.9×10^{-6}	8.8	40	135	310
	5.0	2.9×10^{-4}	1.6	4.8	14.5	38
	6.0	1.1×10^{-3}	.25	.85	3.3	7.7
	7.0	4.4×10^{-3}	.09	.16	.88	2.1

[a]Tests showing effects of fixture tightness (fig. 6).

L-330

TABLE 4.- TENSILE CREEP RESULTS FOR 7075-T6 ALUMINUM-ALLOY SHEET

Temperature, °F	Stress, ksi	Minimum creep rate, hr^{-1}	Time, hr, for creep strains of -				Rupture life, hr
			0.1 percent	0.2 percent	0.5 percent	1.0 percent	
300	32.75	6.1×10^{-5}	2.2	13.5	59	96	158
	32.75	3.5×10^{-5}	----	-----	-----	-----	288
	35.0	----------	----	-----	-----	-----	181
	37.5	6.7×10^{-5}	1.7	11.5	47	64	83.8
	37.5	7.4×10^{-5}	----	-----	-----	-----	100
	41.0	7.5×10^{-5}	1.1	6.8	37	53	71.2
	41.0	1.6×10^{-4}	----	-----	-----	-----	66.6
	46.0	3.9×10^{-4}	.85	3.1	12.1	20	32.5
	46.0	4.5×10^{-4}	----	-----	-----	-----	18.8
	50.0	1.9×10^{-3}	.12	.42	1.7	3.4	7.7
375	17.0	5.3×10^{-5}	3.5	17.0	73	115	139
	17.0	4.0×10^{-5}	----	-----	-----	-----	163
	20.0	1.7×10^{-4}	4.0	10.0	23.5	33.0	42.9
	20.0	9.3×10^{-5}	----	-----	-----	-----	66.6
	20.0	----------	----	-----	-----	-----	53.7
	22.5	2.2×10^{-4}	3.2	7.5	15.8	20.5	27.1
	22.5	1.8×10^{-4}	----	-----	-----	-----	34.9
	25.0	3.8×10^{-4}	1.7	43	9.7	13.0	17.6
	30.0	5.0×10^{-4}	.75	2.4	4.9	6.2	7.2
450	9.0	7.8×10^{-5}	3.3	16.5	67	118	206
	10.0	6.6×10^{-5}	2.1	10.0	53	83	128.8
	10.0	6.3×10^{-5}	----	-----	-----	-----	108
	13.0	3.1×10^{-4}	.88	2.9	11.0	15.3	21.0
	13.0	----------	----	-----	-----	-----	35.5
	15.0	7.5×10^{-4}	.61	1.8	5.7	7.7	9.9
	15.0	8.0×10^{-4}	----	-----	-----	-----	6.3
600	4.0	5.5×10^{-5}	2.0	11.5	56	96	402
	4.0	3.2×10^{-5}	----	-----	-----	-----	-----
	5.0	1.6×10^{-4}	1.3	5.0	22.5	47	144
	5.0	4.3×10^{-4}	----	-----	-----	-----	97.9
	6.0	4.5×10^{-4}	.66	2.1	8.0	18.5	46.8
	6.0	9.0×10^{-4}	----	-----	-----	-----	17.0
	7.0	6.0×10^{-3}	----	.31	.85	1.5	3.4

L-330

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TABLE 5.- COMPRESSIVE CREEP RESULTS FOR 2024-T3

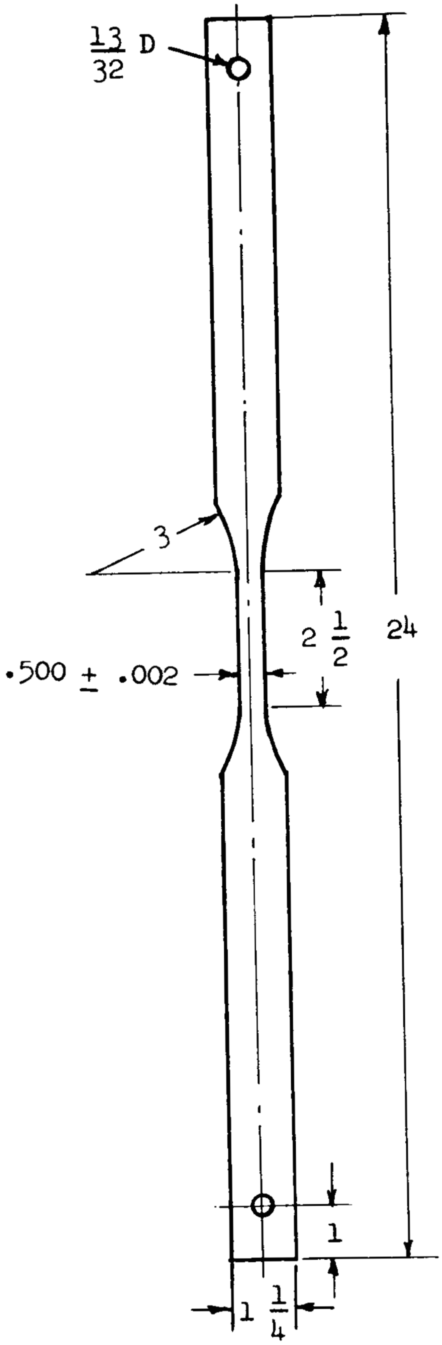
ALUMINUM-ALLOY SHEET

Temperature, °F	Stress, ksi	Minimum creep rate, hr^{-1}	Time, hr, for creep strains of -			
			0.1 percent	0.2 percent	0.5 percent	1.0 percent
300	45.0	5.7×10^{-6}	3.7	3.0	----	-----
	47.5	7.5×10^{-6}	3.1	9.6	----	-----
	50.0	3.4×10^{-6}	3.1	8.3	----	-----
	53.1	1.0×10^{-5}	----	----	----	-----
	53.75	7.2×10^{-6}	1.3	5.9	92	-----
375	29.0	2.9×10^{-5}	----	----	----	-----
	30.0	4.3×10^{-5}	7.7	29.5	98	-----
	33.8	7.1×10^{-5}	----	----	----	-----
	35	7.7×10^{-5}	6.3	18.5	60	123
	40	1.9×10^{-4}	1.7	6.4	14.5	24
	42	2.3×10^{-5}	.17	3.2	9.7	16.2
450	21.7	2.5×10^{-4}	0.95	4.3	15.8	32
	24.1	3.0×10^{-4}	----	----	----	-----
	25.0	4.2×10^{-4}	.6	2.3	9	17.5
	26.5	9.2×10^{-4}	.4	1.4	5.3	10.5
	29.0	2.4×10^{-3}	.17	.6	2.8	4.9
	29.0	2.1×10^{-3}	----	----	----	-----
600	4.0	4.9×10^{-5}	3.9	14.5	78	200
	6.0	2.8×10^{-4}	1.6	5.1	16	34.5
	8.0	7.4×10^{-4}	.7	1.8	5.4	11.0

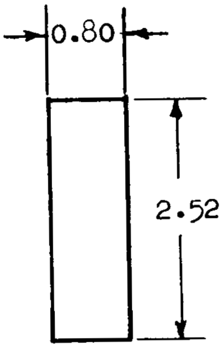
TABLE 6.- TENSILE CREEP RESULTS FOR 2024-T3 ALUMINUM-ALLOY SHEET

Temperature, °F	Stress, ksi	Minimum creep rate, hr^{-1}	Time, hr, for creep strains of -				Rupture life, hr
			0.1 percent	0.2 percent	0.5 percent	1.0 percent	
300	47.5	2.9×10^{-5}	0.18	0.31	0.78	26.0	153
	50	4.4×10^{-5}	----	.17	.37	1.6	83.6
	53.75	1.6×10^{-4}	----	-----	.08	.37	36.0
375	25	2.2×10^{-5}	6.0	34.5	175	310	478
	30	1.1×10^{-4}	2.2	9.6	67	133	240
	35	1.7×10^{-4}	2.0	5.5	22	43.5	63.2
	37.5	5.4×10^{-4}	----	-----	------	------	28.5
	40.0	7.1×10^{-4}	.37	1.7	4.1	6.6	12.5
	42.0	1.7×10^{-3}	.57	1.1	2.2	3.2	5.1
450	20.0	1.5×10^{-4}	1.2	5.3	2.5	57	106
	25.0	3.4×10^{-4}	.60	2.5	10.6	23.5	44.4
	27.5	7.3×10^{-4}	.32	.9	3.5	5.6	10.6
	30.0	2.6×10^{-3}	.14	.41	1.6	2.7	5.4
600	4.0	5.0×10^{-5}	2.4	16	78	145	304
	6.0	3.1×10^{-4}	.8	2.6	11.4	22.5	36.6
	8.0	1.4×10^{-3}	.35	1.1	3.3	5.9	12.2

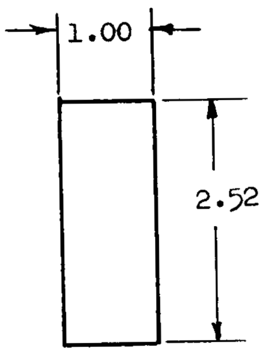
L-330



(a) Tensile stress-strain and tensile creep specimen.



(b) Compressive creep specimen.



(c) Compressive stress-strain specimen.

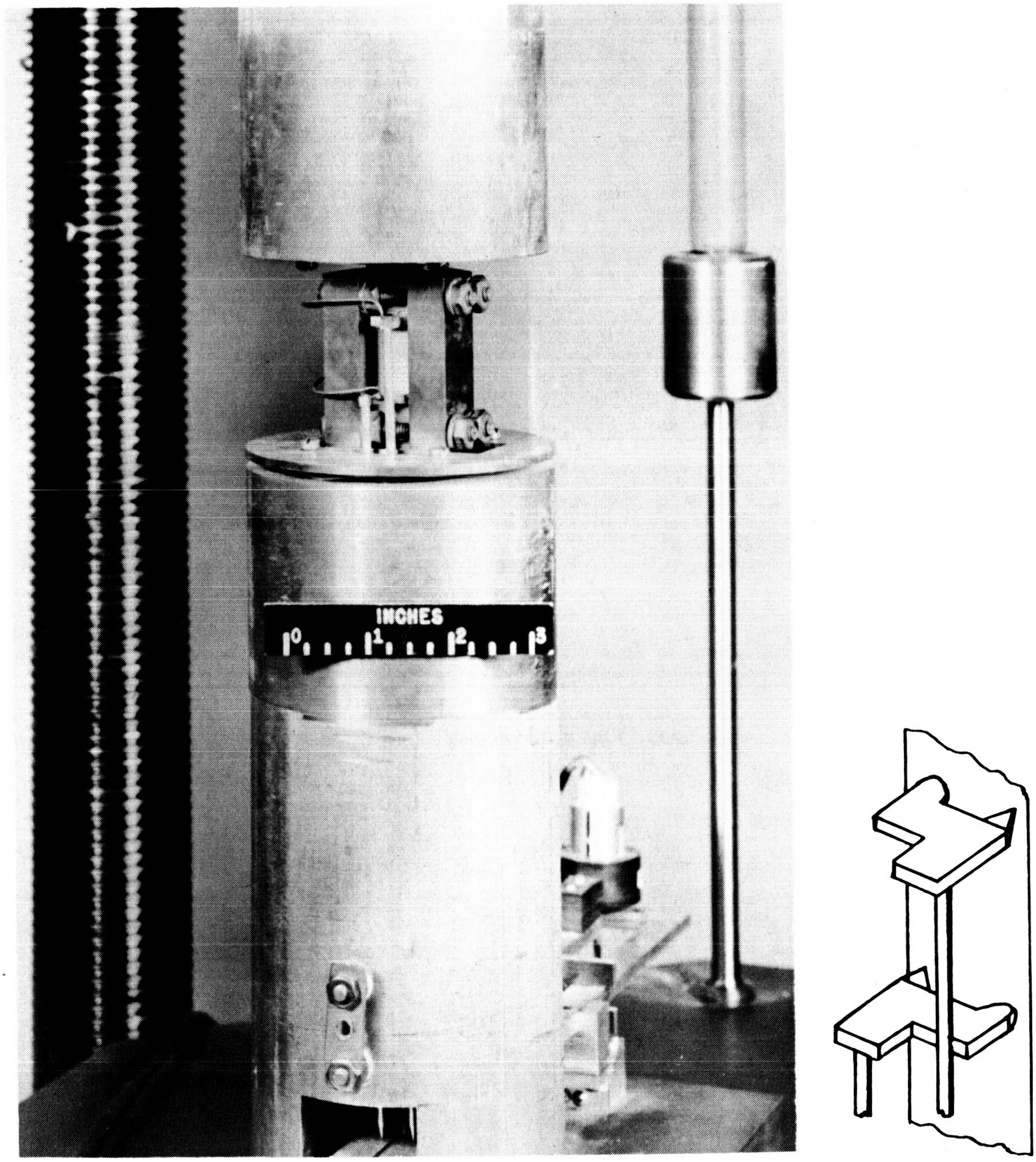
Figure 1.- Tensile and compressive stress-strain and creep specimens. All dimensions are in inches.

L-330

L-57-1965

Figure 2.- Compressive creep testing machine and auxiliary equipment.

L-330



L-57-1932

(a) Loading rams and V-groove fixture.

(b) Gage point and stabilizing arrangement.

Figure 3.- Loading rams and V-groove fixture with specimen in place and extensometer detail.

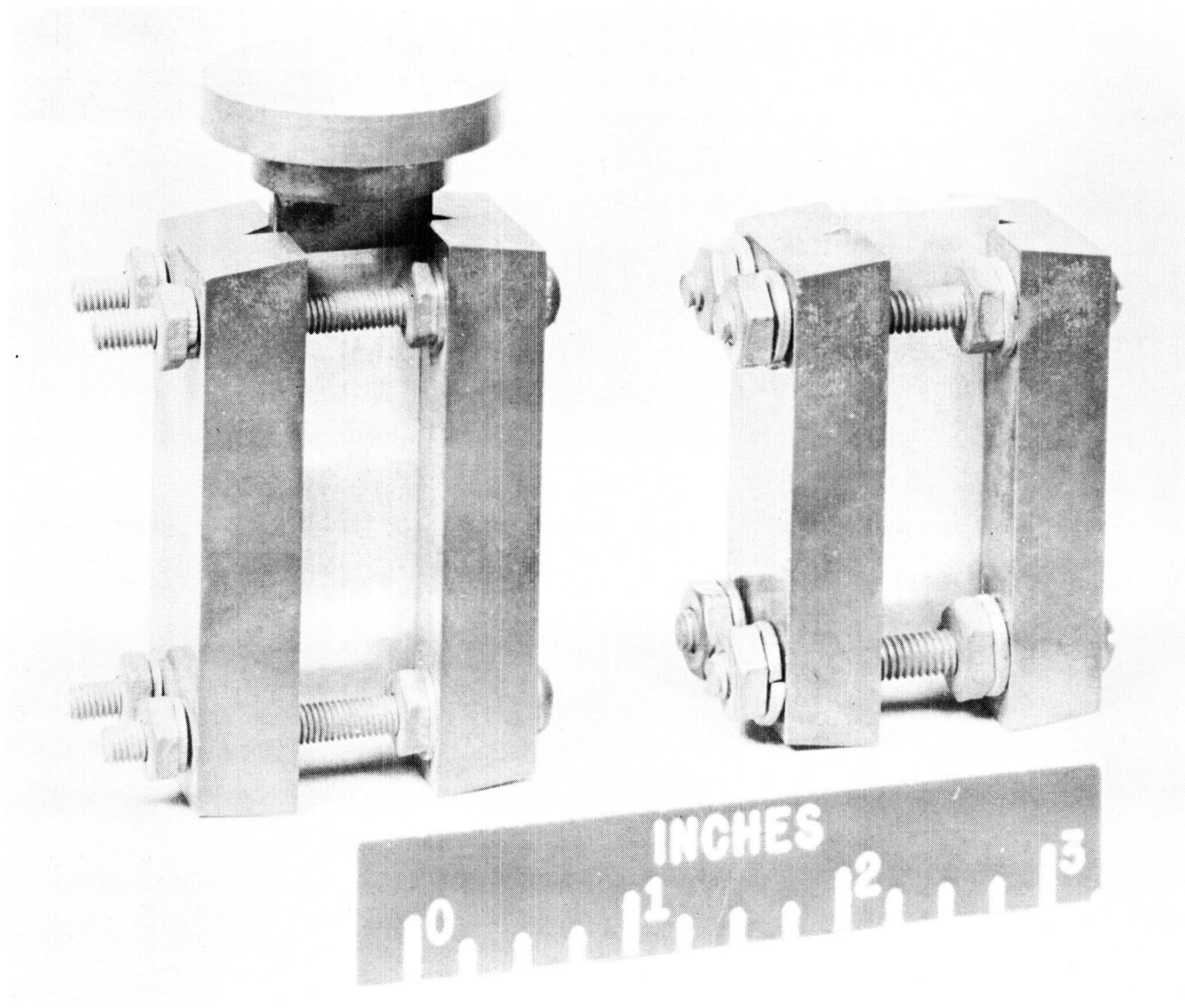
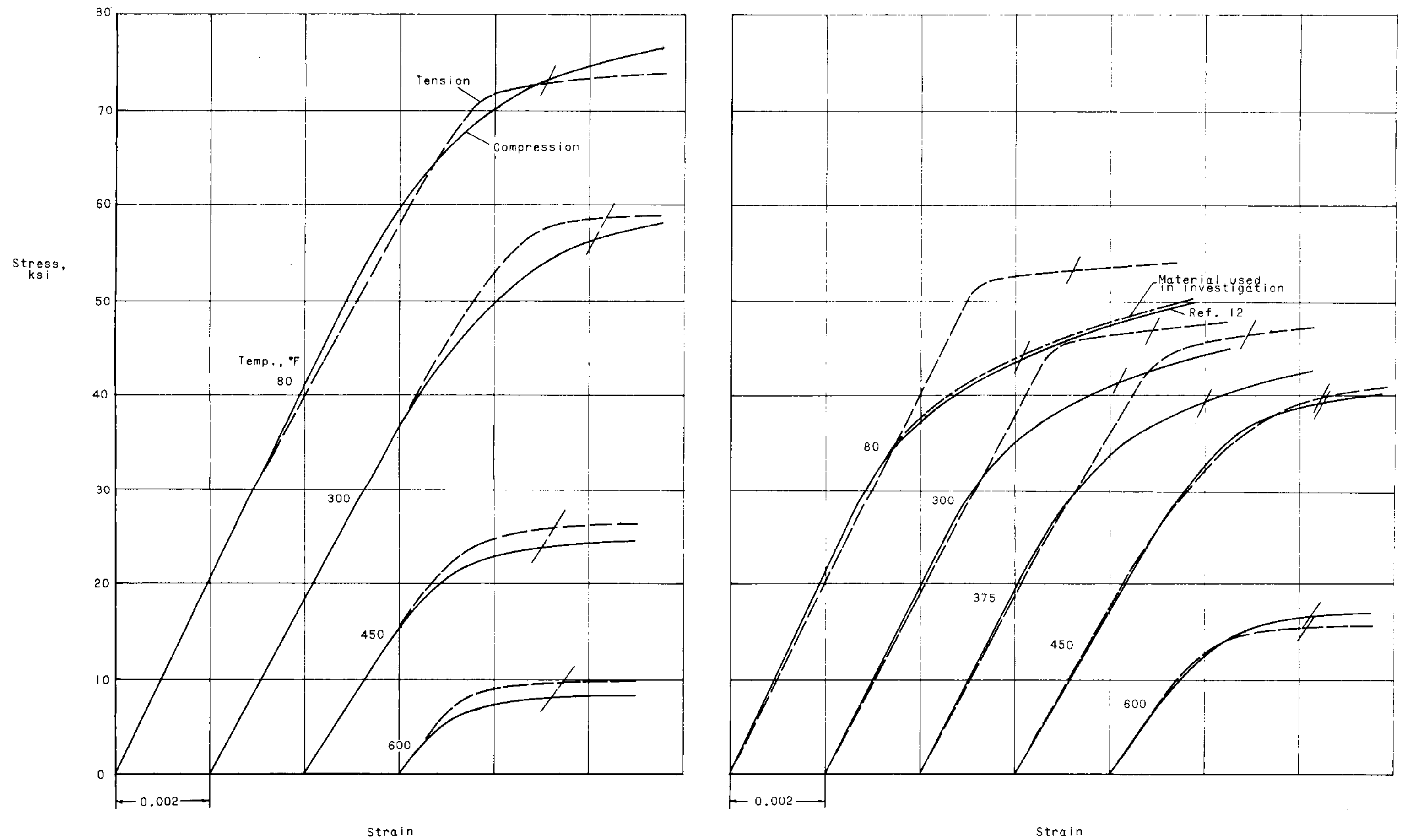


Figure 4.- Two types of V-groove fixtures. L-57-1933



(a) 7075-T6.

(b) 2024-T3.

Figure 5.- Elevated-temperature compressive and tensile stress-strain curves for 7075-T6 and 2024-T3 aluminum-alloy sheet.

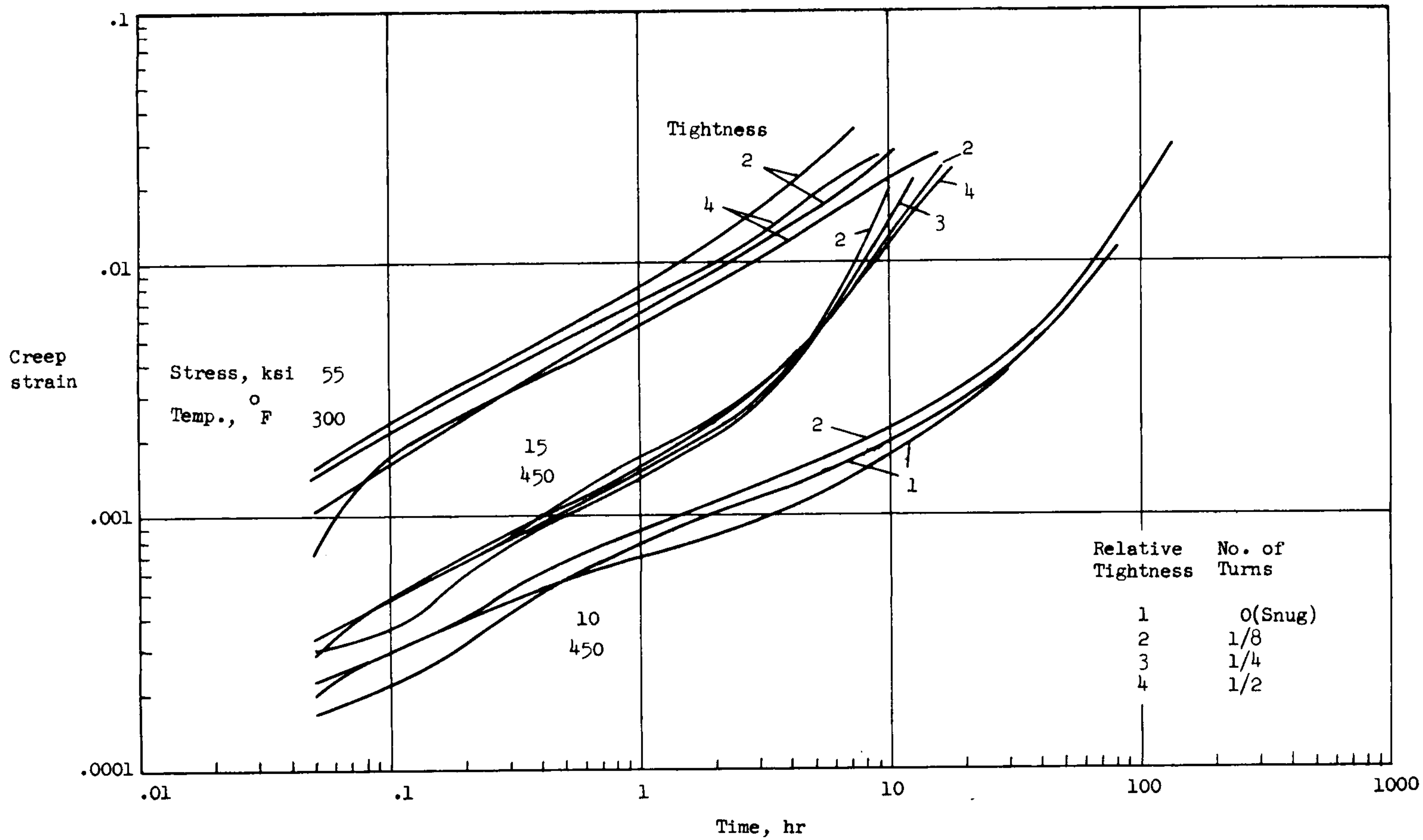
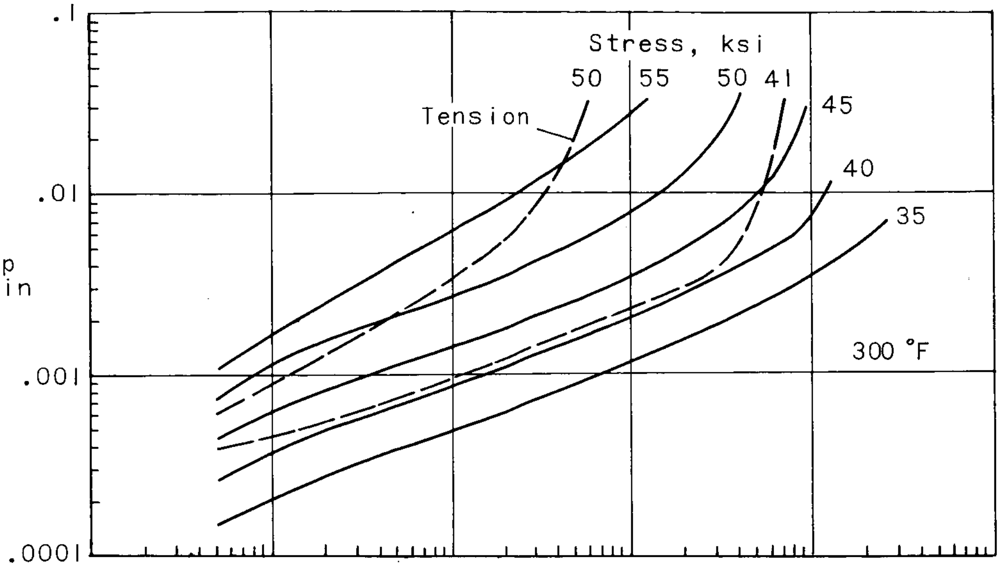
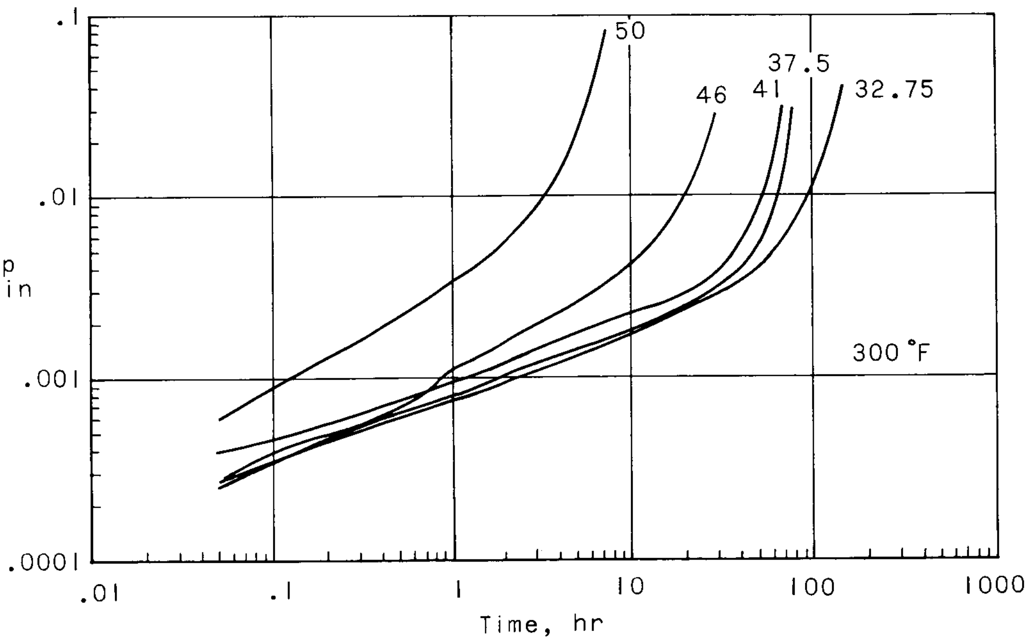


Figure 6.- Effect of fixture tightness on compressive creep of 7075-T6 aluminum-alloy sheet at 300° and 450° F.

L-330

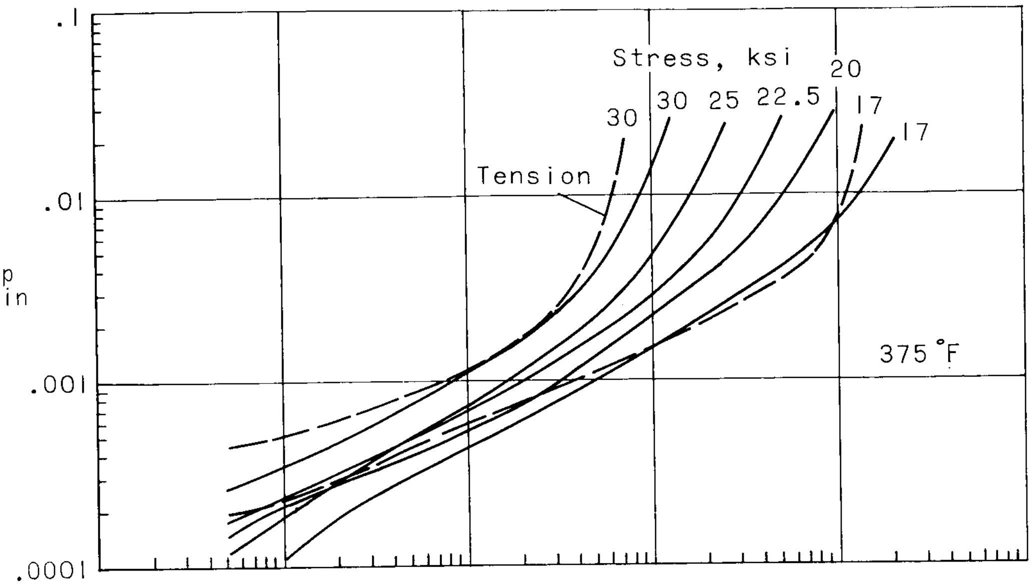


(a) Compression.

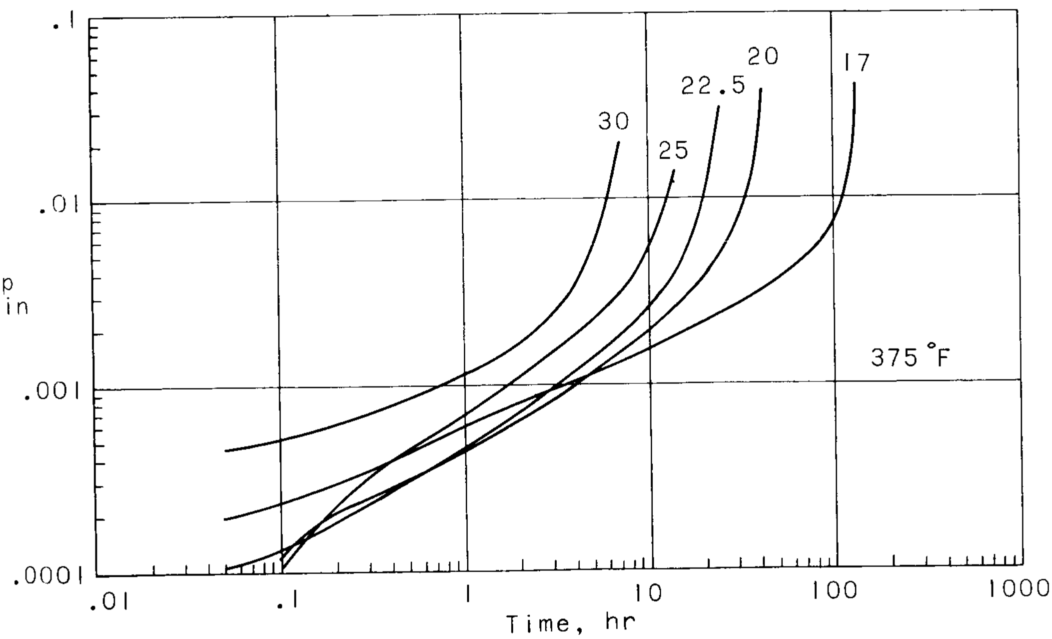


(b) Tension.

Figure 7.- Compressive and tensile creep strain-time curves for 7075-T6 aluminum-alloy sheet at 300° F.



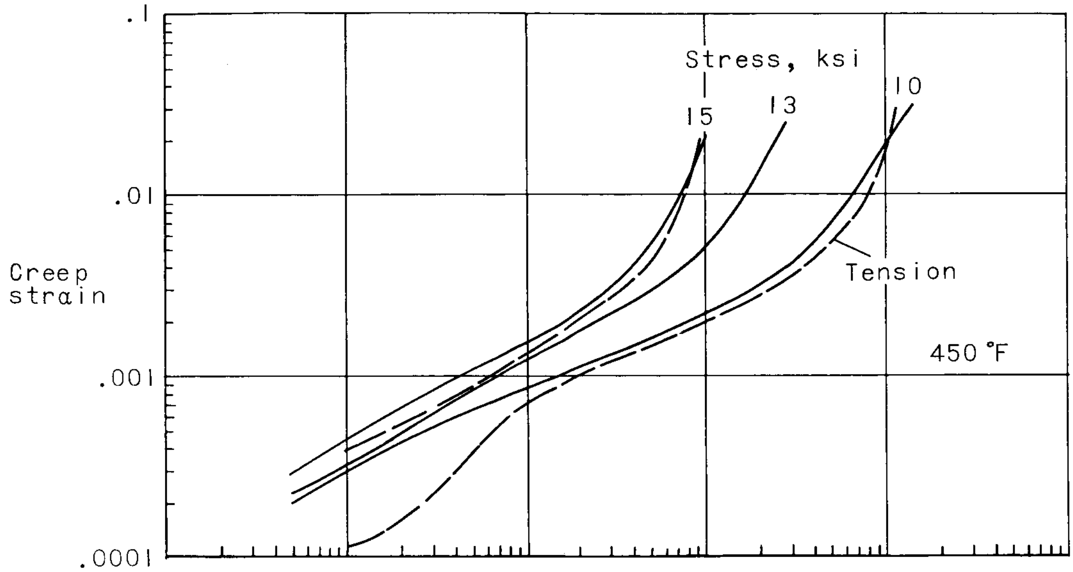
(a) Compression.



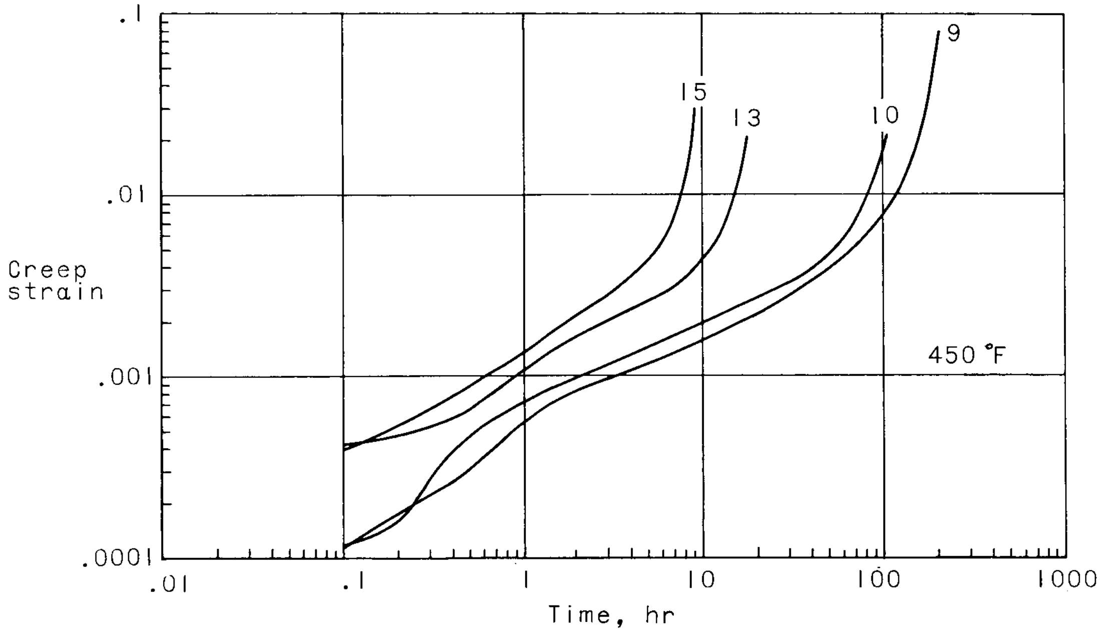
(b) Tension.

Figure 8.- Compressive and tensile creep strain-time curves for 7075-T6 aluminum-alloy sheet at 375° F.

L-330

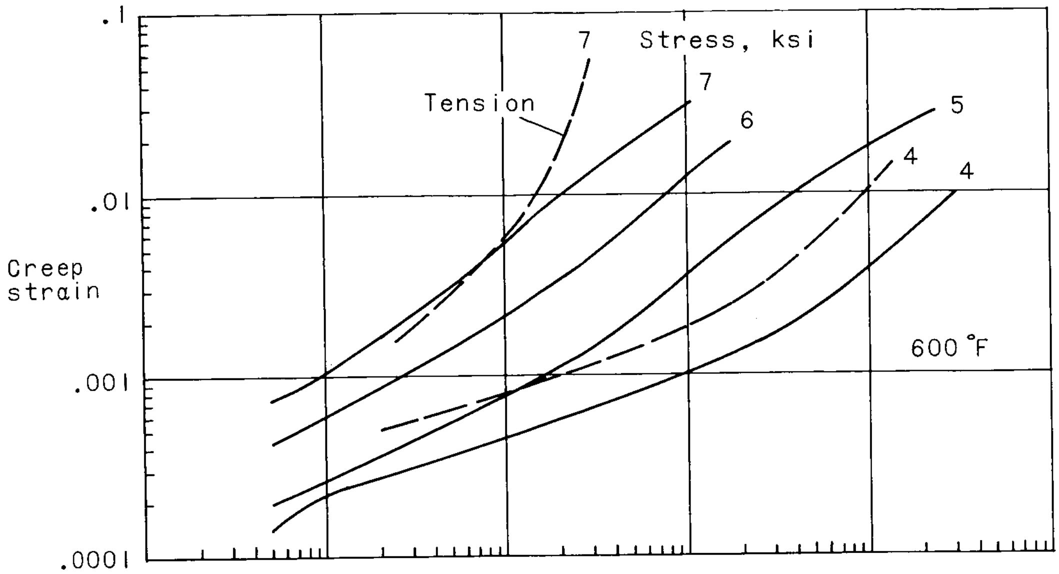


(a) Compression.

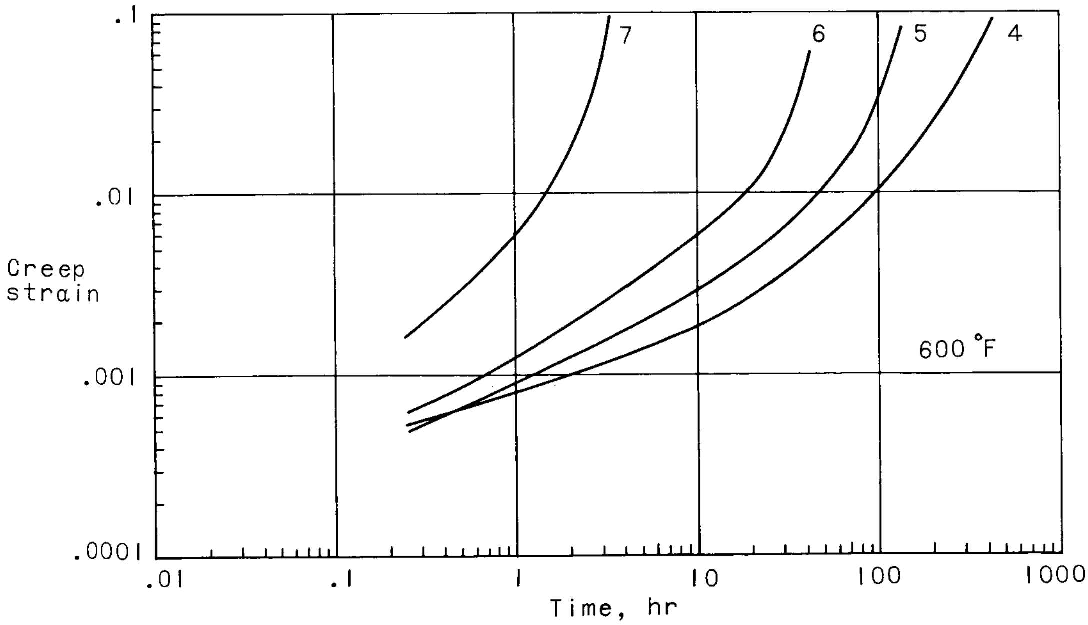


(b) Tension.

Figure 9.- Compressive and tensile creep strain-time curves for 7075-T6 aluminum-alloy sheet at 450° F.



(a) Compression.

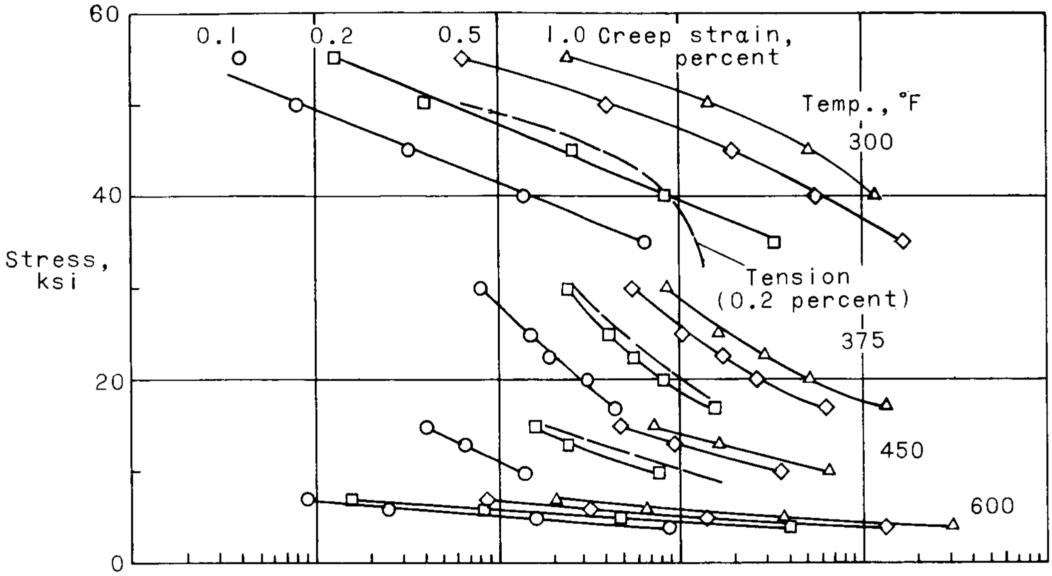


(b) Tension.

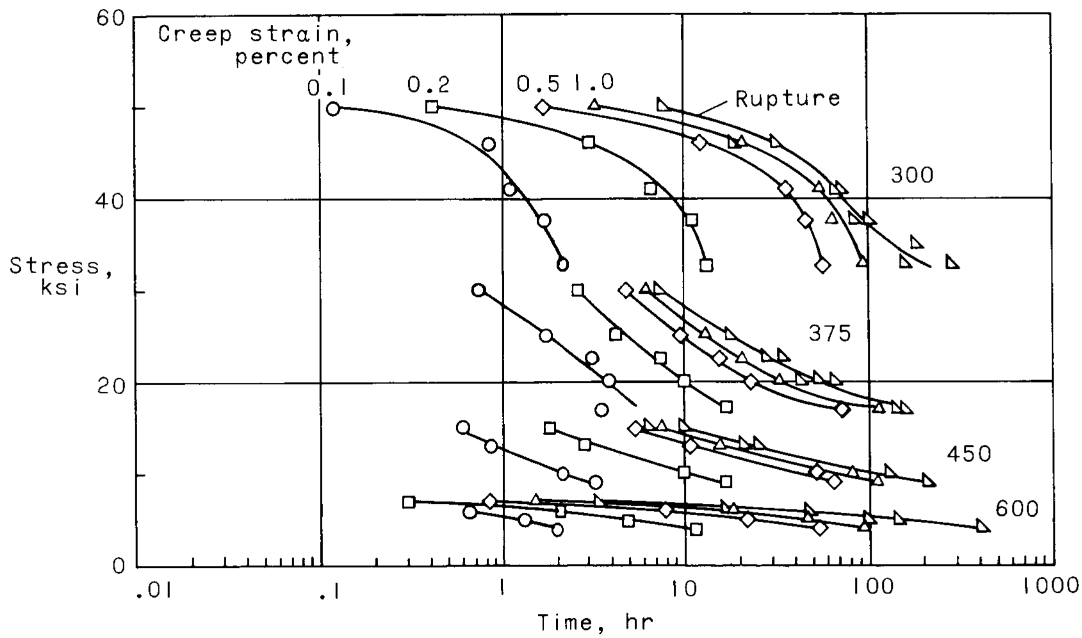
Figure 10.- Compressive and tensile creep strain-time curves for 7075-T6 aluminum-alloy sheet at 600° F.

L-330

L-330



(a) Compression.



(b) Tension.

Figure 11.- Compressive and tensile stress-time curves for 7075-T6 aluminum-alloy sheet for creep strain from 0.1 to 1.0 percent at 300°, 375°, 450°, and 600° F.

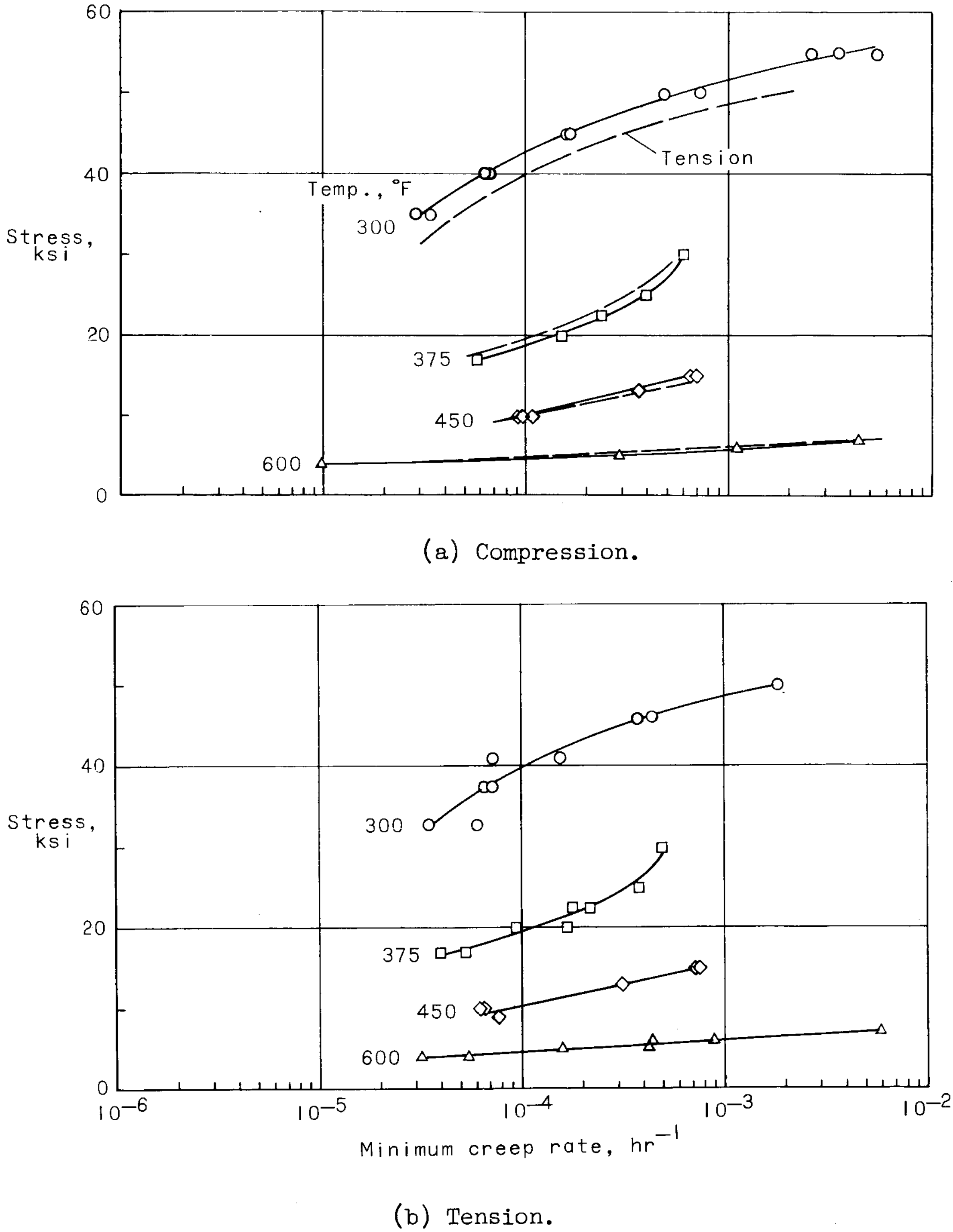


Figure 12.- Minimum creep rates in compression and tension for 7075-T6 aluminum-alloy sheet at 300°, 375°, 450°, and 600° F.

L-330

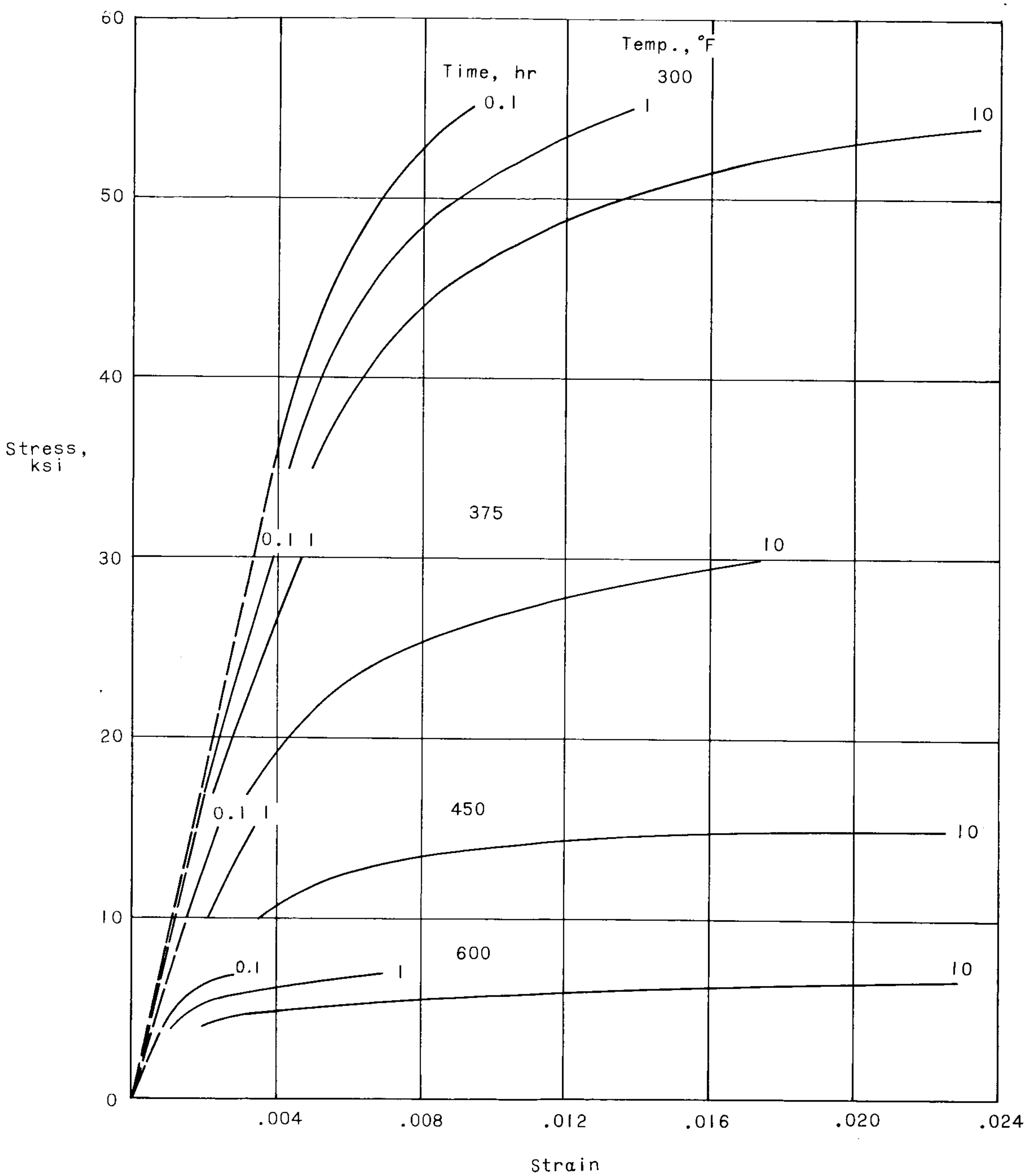


Figure 13.- Isochronous compressive stress-strain curves for 7075-T6 aluminum-alloy sheet for 0.1, 1, and 10 hours at 300°, 375°, 450°, and 600° F.

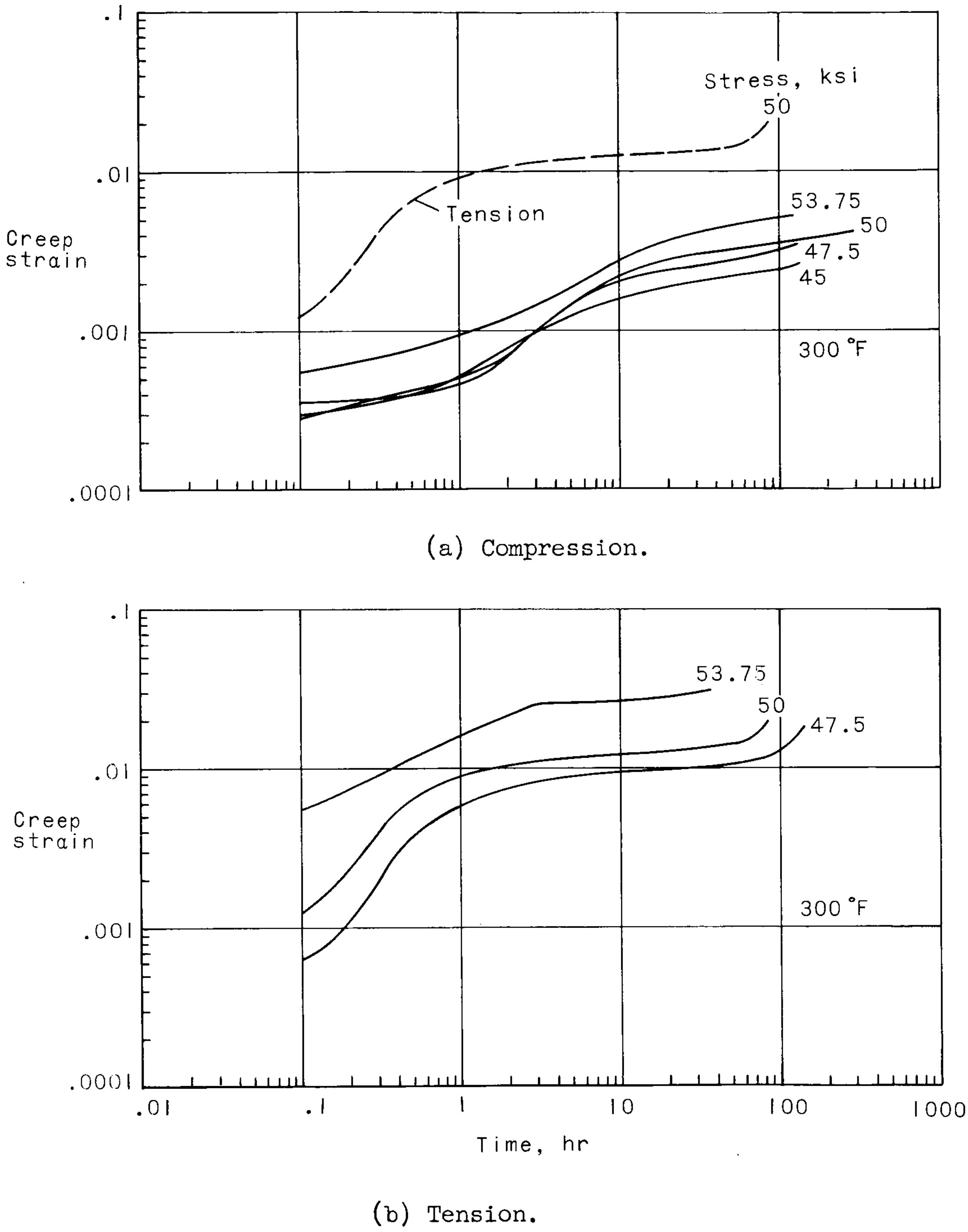
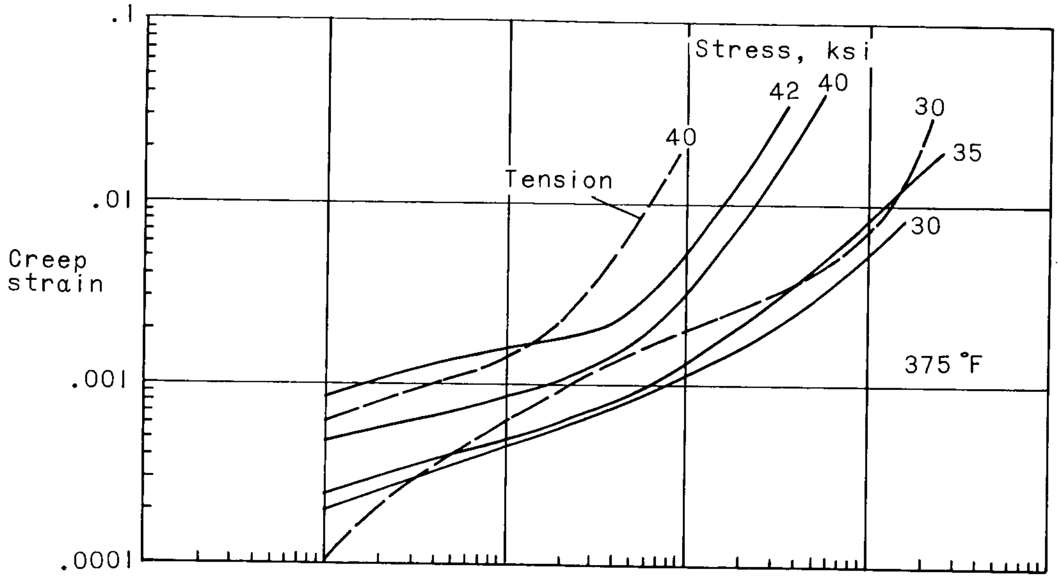
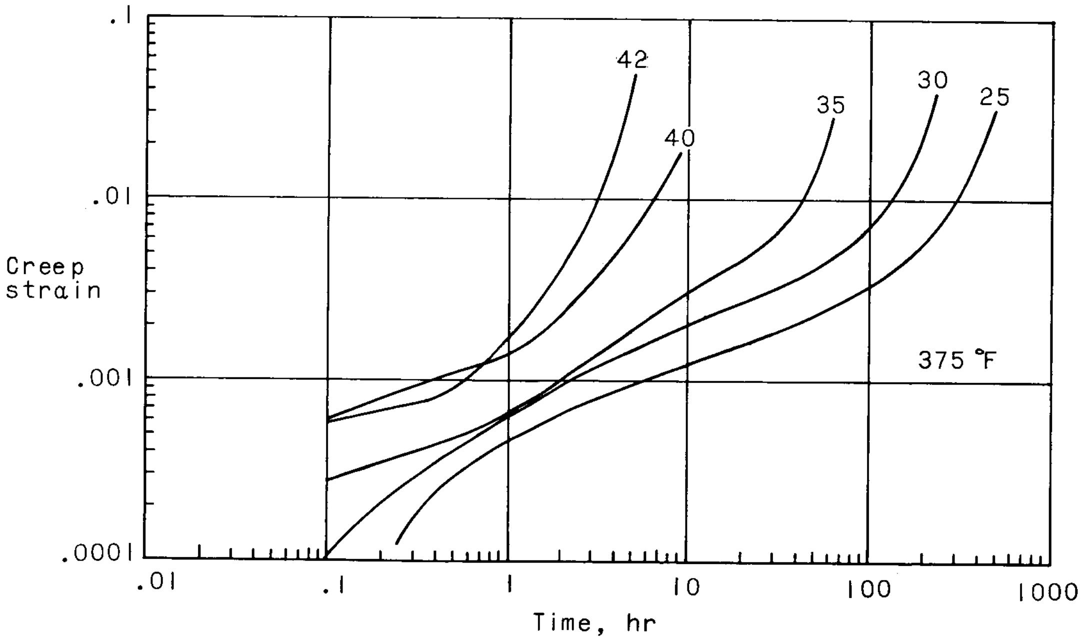


Figure 14.- Compressive and tensile creep strain-time curves for 2024-T3 aluminum-alloy sheet at 300° F.

L-330

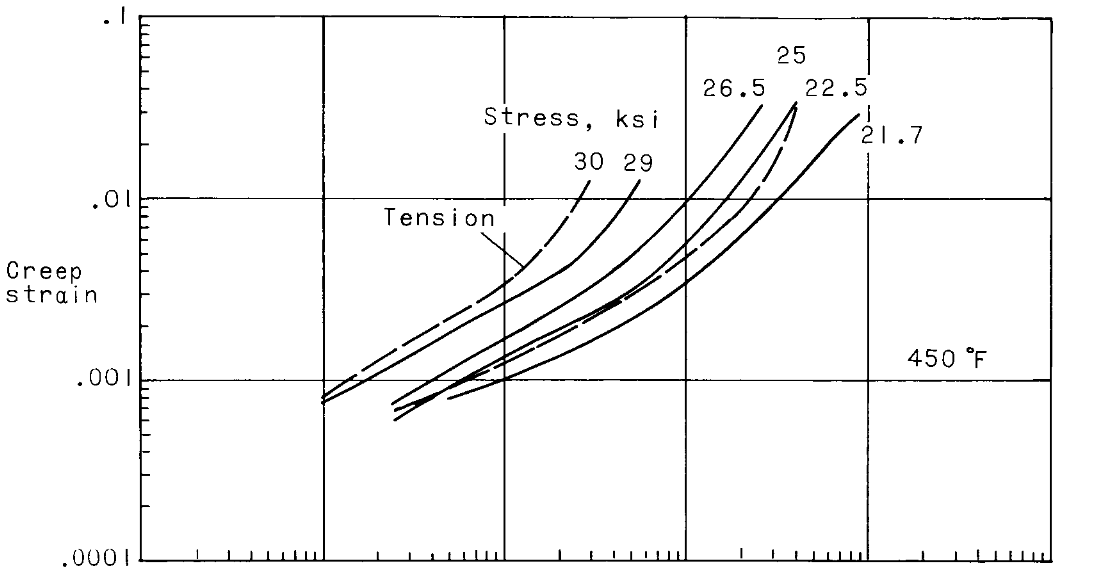


(a) Compression.

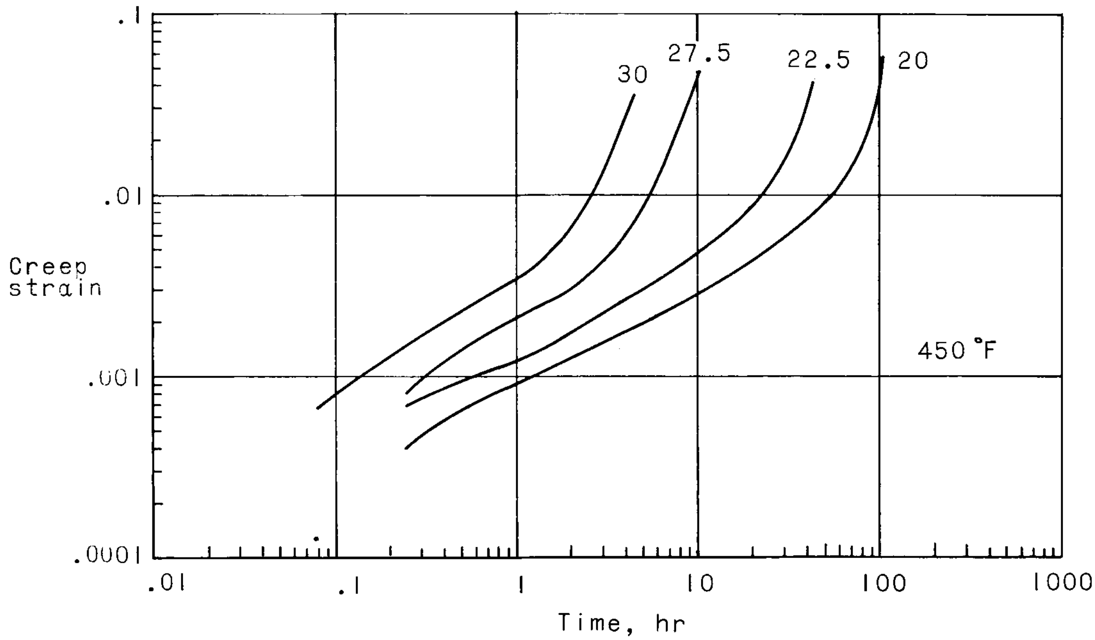


(b) Tension.

Figure 15.- Compressive and tensile creep strain-time curves for 2024-T3 aluminum-alloy sheet at 375° F.



(a) Compression.

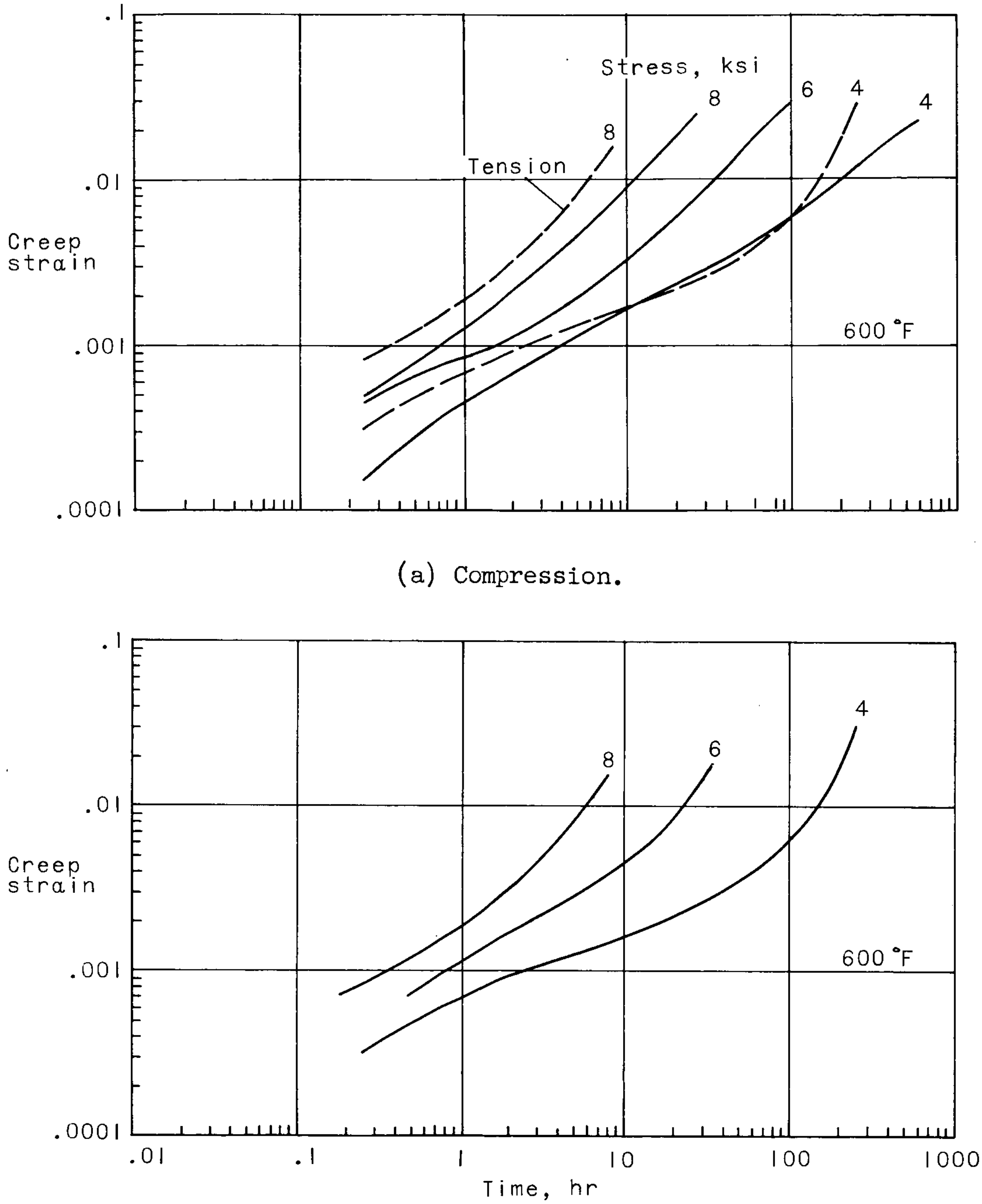


(b) Tension.

Figure 16.- Compressive and tensile creep strain-time curves for 2024-T3 aluminum-alloy sheet at 450° F.

L-330

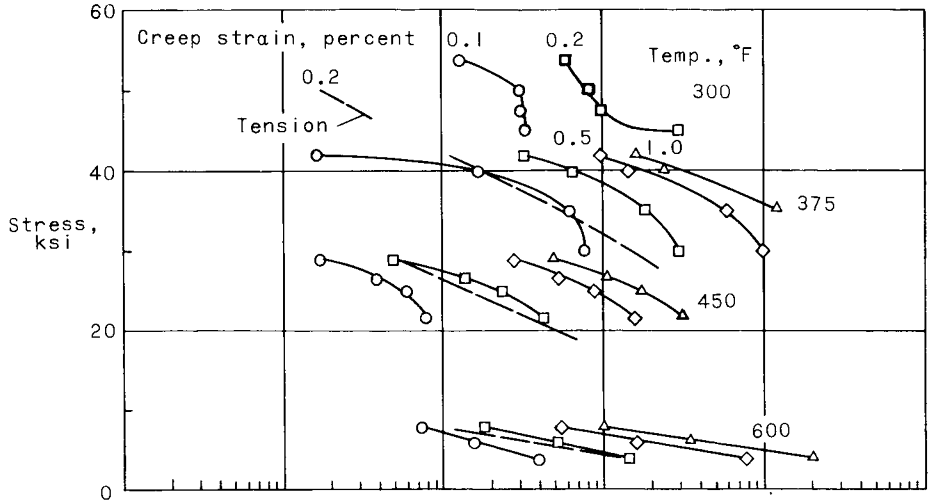
L-330



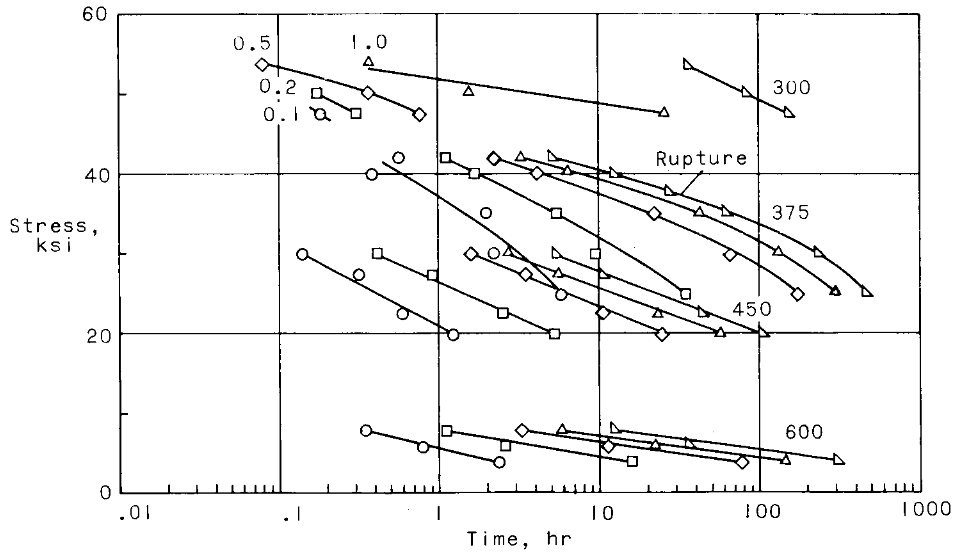
(a) Compression.

(b) Tension.

Figure 17.- Compressive and tensile creep strain-time curves for 2024-T3 aluminum-alloy sheet at 600° F.



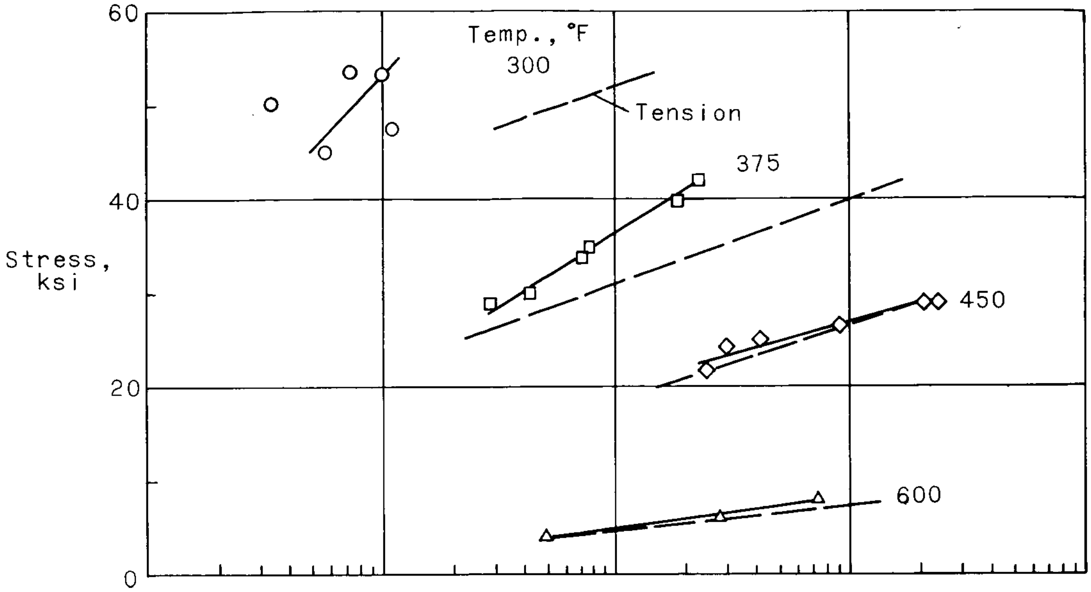
(a) Compression.



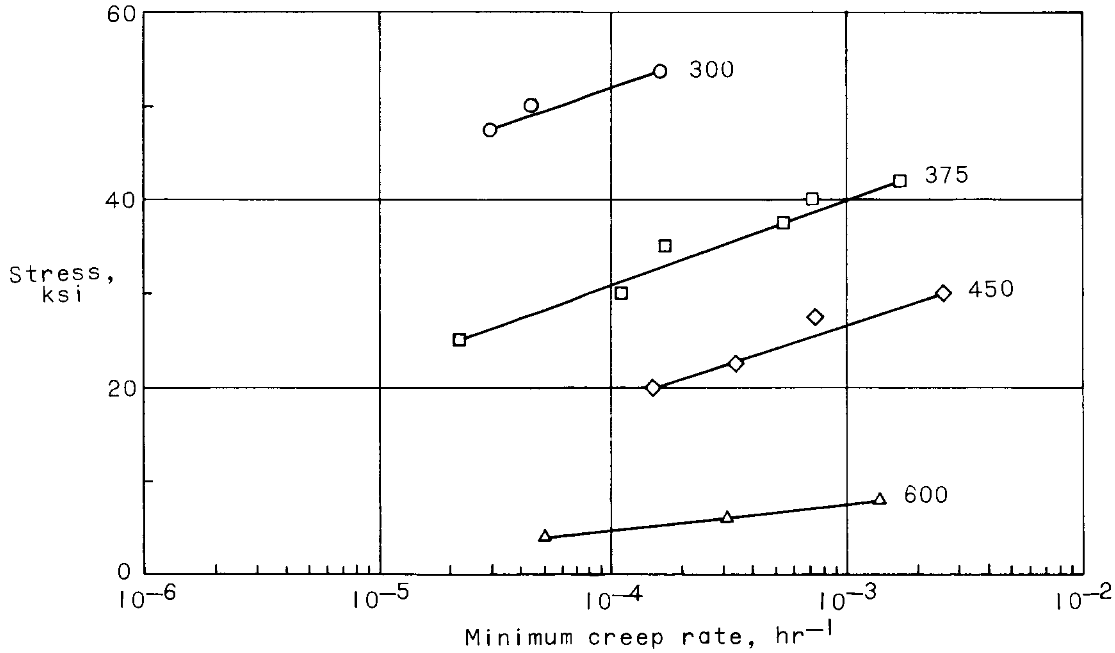
(b) Tension.

Figure 18.- Compressive and tensile stress-time curves for 2024-T3 aluminum-alloy sheet for creep strain from 0.1 to 1.0 percent at 300°, 375°, 450°, and 600° F.

L-330



(a) Compression.



(b) Tension.

Figure 19.- Minimum creep rates in compression and tension for 2024-T3 aluminum-alloy sheet at 300°, 375°, 450°, and 600° F.

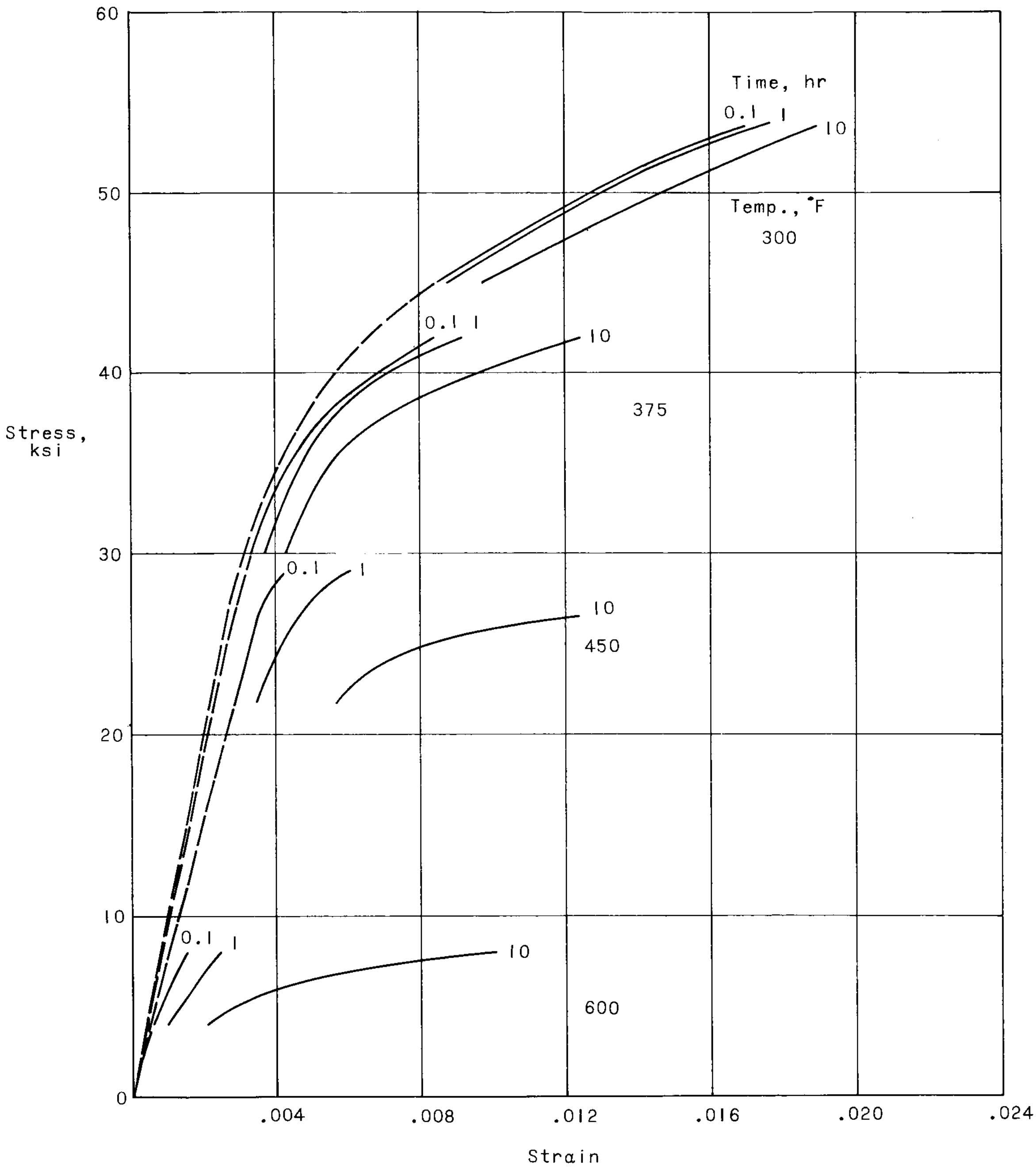


Figure 20.- Isochronous compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 300°, 375°, 450°, and 600° F.